

**SPIN-FLAVOR DECOMPOSITION IN POLARIZED
SEMI-INCLUSIVE DEEP INELASTIC SCATTERING
EXPERIMENTS AT JEFFERSON LAB**

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A Jefferson Lab experiment proposal was discussed in this talk. The experiment is designed to measure the beam-target double-spin asymmetries A_{1n}^h in semi-inclusive deep-inelastic $\vec{n}(\vec{e}, e' \pi^+)X$ and $\vec{n}(\vec{e}, e' \pi^-)X$ reactions on a longitudinally polarized ${}^3\text{He}$ target. In addition to A_{1n}^h , the flavor non-singlet combination $A_{1n}^{\pi^+ - \pi^-}$, in which the gluons do not contribute, will be determined with high precision to extract $\Delta d_v(x)$ independent of the knowledge of the fragmentation functions. The data will also impose strong constraints on quark and gluon polarizations through a global NLO QCD fit.

1. Introduction

Polarized semi-inclusive deep-inelastic scattering (SIDIS) experiments can be used to study the spin-flavor structure of the nucleon, as has been demonstrated first by the SMC experiment ¹. Recently, the HERMES experiment published results of a leading order spin-flavor decomposition from polarized proton and deuteron SIDIS asymmetry data, and for the first time extracted the \bar{u}, \bar{d} and $s = \bar{s}$ sea quark polarizations ². The HERMES “purity” method of spin-flavor decomposition relies on the assumption that the quark fragmentation process and the experimental phase spaces are well-understood such that a LUND model based Monte Carlo simulation can reliably reproduce the probability correlations between the detected hadrons and the struck quarks ². The accuracies on the knowledge of the fragmentation process played a crucial role in extracting the polarized parton distributions in this method.

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As an alternate method, Christova and Leader pointed out ³ that if the flavor non-singlet combination $A_1^{\pi^+ - \pi^-}$ is measured, the quark polarization Δu_v , Δd_v and $\Delta \bar{u} - \Delta \bar{d}$ can be extracted at leading order without the complication of fragmentation functions. In fact, information on the valence quark polarizations will be well preserved at any QCD order in $A_1^{\pi^+ - \pi^-}$ since gluons do not contribute to this flavor non-singlet observable. At leading order, assuming isospin symmetry and charge conjugation, the fragmentation functions cancel exactly in $A_1^{\pi^+ - \pi^-}$ and the s -quarks do not contribute, so that:

$$A_{1p}^{\pi^+ - \pi^-} \equiv \frac{\Delta \sigma_p^{\pi^+} - \Delta \sigma_p^{\pi^-}}{\sigma_p^{\pi^+} - \sigma_p^{\pi^-}} = \frac{A_{1p}^{\pi^+} - A_{1p}^{\pi^-} \cdot \sigma_p^{\pi^-} / \sigma_p^{\pi^+}}{1 - \sigma_p^{\pi^-} / \sigma_p^{\pi^+}} = \frac{4\Delta u_v - \Delta d_v}{4u_v - d_v},$$

$$A_{1n}^{\pi^+ - \pi^-} \equiv \frac{\Delta \sigma_n^{\pi^+} - \Delta \sigma_n^{\pi^-}}{\sigma_n^{\pi^+} - \sigma_n^{\pi^-}} = \frac{A_{1n}^{\pi^+} - A_{1n}^{\pi^-} \cdot \sigma_n^{\pi^-} / \sigma_n^{\pi^+}}{1 - \sigma_n^{\pi^-} / \sigma_n^{\pi^+}} = \frac{4\Delta d_v - \Delta u_v}{4d_v - u_v}. \quad (1)$$

Thus, measurements of $A_1^{\pi^+ - \pi^-}$ on the proton and the neutron can determine Δu_v and Δd_v . On the other hand, another non-singlet quantity is constrained by the inclusive data:

$$g_1^p(x, Q^2) - g_1^n(x, Q^2) = \frac{1}{6} [(\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d})] |_{LO}. \quad (2)$$

If one is only interested in flavor non-singlet quantities, such as $\Delta \bar{u} - \Delta \bar{d}$, the goal of SIDIS experiments is reduced to obtaining information on $\Delta u_v - \Delta d_v$, and the polarized sea asymmetry can be extracted at leading order :

$$(\Delta \bar{u} - \Delta \bar{d}) |_{LO} = 3(g_1^p - g_1^n) |_{LO} - \frac{1}{2}(\Delta u_v - \Delta d_v) |_{LO}. \quad (3)$$

At next-to-leading order, QCD global fits of data from both inclusive and semi-inclusive reactions have become the state of the art ⁴. One expects that the next generation of polarized parton distribution functions will take advantage of improvements on both quality and volume of SIDIS data from HERMES, COMPASS and Jefferson Lab. Although there are data available and experiments planned ⁶ with polarized proton and deuteron targets, there has been a lack of attention in obtaining SIDIS data on the neutron from a polarized ³He target.

2. A proposal of polarized ³He SIDIS at Jefferson Lab

An experiment proposal ⁷ has been developed recently at Jefferson Lab Hall A to provide high statistics neutron SIDIS data using a polarized ³He target. The plan is to measure the double-spin asymmetries A_{1n}^h in $\vec{n}(\vec{e}, e'h)X$

reactions ($h = \pi^+$ and π^- , with K^+ and K^- as by-products) with a 6 GeV polarized electron beam on a longitudinally polarized ^3He target at a luminosity of $10^{36} \text{ sec}^{-1}\text{cm}^{-2}$. The Hall A left-HRS spectrometer with its septum magnet will detect the leading hadrons at 6° ($\Delta\Omega \approx 5 \text{ msr}$) with a momentum of $2.40 \text{ GeV}/c$ ($z_h = E_h/\nu \sim 0.5$) for either positive or negative polarity. The recently constructed BigBite spectrometer ($\Delta\Omega \approx 60 \text{ msr}$) will be used as the electron detector at 30° to detect the scattered electrons with $0.8 \sim 2.1 \text{ GeV}/c$ in coincidence ($0.12 < x < 0.41$, $Q^2 = 1.21 \sim 3.14 \text{ GeV}^2$). Since the π^- and π^+ phase spaces are identical and the detection efficiencies can be well-controlled, relative π^-/π^+ yield ratios can be easily determined such that the flavor non-singlet combination $A_{1n}^{\pi^+ - \pi^-}$ can be constructed.

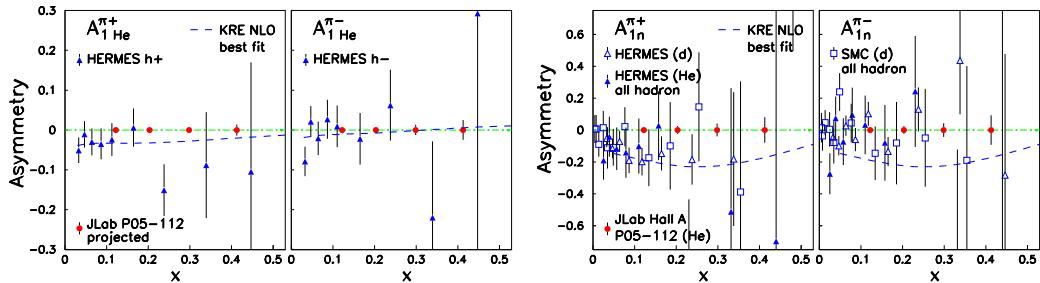


Figure 1. The expected statistical uncertainties of $A_{1He}^{\pi^+}$ (left) and $A_{1n}^{\pi^-}$ (right) of Jefferson Lab proposal P05-112. The SMC and the HERMES deuteron data ^{1,2} have been translated into neutron asymmetries assuming leading order x - z factorization. The dashed curves are from the next-to-leading order global fit ⁴ of the existing data.

For 30 days of beam time, assuming 75% beam polarization and 42% target polarization, the statistical accuracy of $A_{1He}^{\pi^+}$ can be improved by an order of magnitude compared to earlier HERMES data ⁵, as shown in Fig. 1. Significant improvements are expected on $A_{1n}^{\pi^-}$ when compared to the deuteron data from SMC and HERMES. Following the Christova-Leader method of Eq. 1, Δd_v can be extracted from $A_{1n}^{\pi^+ - \pi^-}$, as shown together in Fig. 2 with the HERMES data ² from the purity method. When combined with the upcoming proton data ⁶ of JLab experiment E04-113, sea flavor asymmetries can be extracted at leading order following Eq. 3. With a factor of five improvement on statistical accuracy compared to that of the HERMES $\Delta\bar{u} - \Delta\bar{d}$ results, this experiment might provide the first opportunity to discover a possible polarized sea asymmetry.

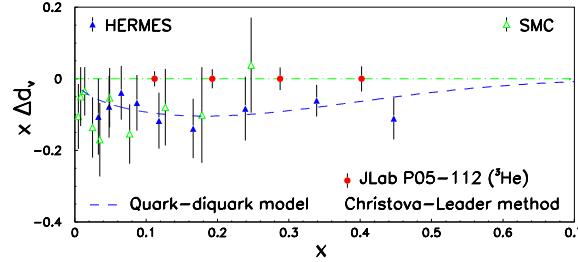


Figure 2. The statistical accuracy of Δd_v compared to the SMC ¹ and the HERMES data ². The dashed curve is from a covariant quark-diquark model calculation ⁸ of Cloet *et al.*

Adding this set of ${}^3\text{He}$ data to the global NLO QCD fit, a factor of three improvement on sea quark polarization moments can be expected ⁴, as shown in Fig. 3. Indirectly, this data set will also improve the constraints on the gluon polarization Δg by a factor of three, comparable to the impact of the expected RHIC-2007 $A_{LL}^{\pi^0}$ data, as shown in Fig. 4. The reason for this sensitivity is because Δg is obtained in the global fit through the Q^2 -evolutions of the inclusive structure functions g_1 which are coupled to the sea distribution. Once the valence distribution is reasonably separated from the sea with the SIDIS data, the gluon polarization can be better constrained in a global fit.

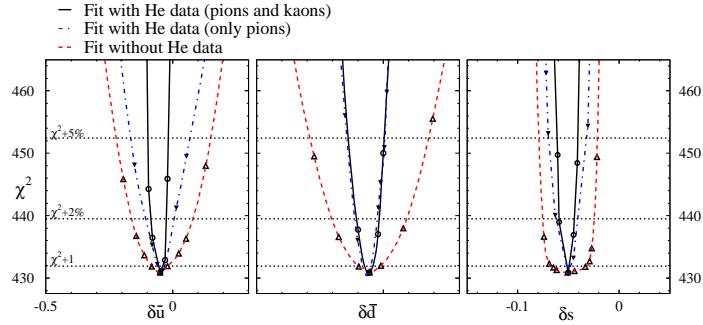


Figure 3. The expected improvement on the sea polarization moments in NLO global fit ⁴. The dashed lines are the existing constraints, the dot-dashed and the solid lines are the constraints after adding pion data and/or kaon data from this proposal. The horizontal lines correspond to a deviation of $\chi^2 + 1$, $\chi^2(1 + 2\%)$ and $\chi^2(1 + 5\%)$ from the best fit.

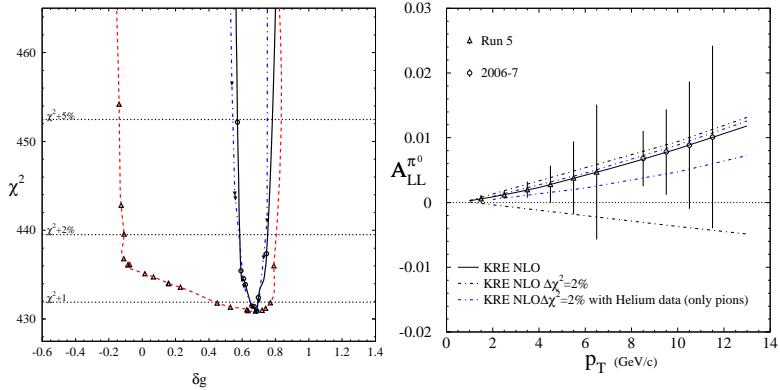


Figure 4. The constraint on the moment of the gluon polarization⁴ by this measurement (left, curves as labeled in Fig. 3) is compared with that from the expected RHIC-2007 $A_{LL}^{\pi^0}$ data (right). In the right panel, the area covered between the two inner blue dot-dashed lines corresponds to the $\chi^2(1+2\%)$ crossover region with the blue-dashed line on the left panel.

3. Conclusions

A Jefferson Lab Hall A experiment proposal to measure polarized ^3He SIDIS asymmetries in $\vec{n}(\vec{e}, e'h)X$ reactions was discussed. The proposed measurement will dramatically improve the precision of the world data set of A_{1n}^h and our knowledge of $\Delta d_v(x)$. Strong constraints on quark and gluon polarizations can be imposed through a global NLO QCD analysis.

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